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Measurements on the radiations from the decay of I^{134} and I^{133}

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With 5 figures in the text

ABSTRACT

The beta and gamma radiations from the radioactive decay of the isotopes I^{134} and I^{133} have been studied by means of magnetic beta-spectrometers and scintillation techniques.

A Fermi analysis of the beta-ray spectrum from the decay of I^{134} shows that it is very complex. The maximum energy is found to be 2.35 MeV and the measured energies of two further components are 1.57 MeV and 1.3 MeV. The energies of the gamma rays following the decay of I^{134} are 0.138, 0.21, 0.42, 0.63, 0.86 (there seem to be two gamma rays with about this energy), 1.07, 1.14, 1.45, 1.62 and 1.80 MeV.

Coincidence experiments have been carried out and the beta disintegration energy (Q_{β^-} value) for the decay of I^{134} to Xe^{134} is estimated as 4.1 MeV.

As regards the decay of I^{133}, the maximum energy of the beta-ray spectrum is found to be 1.27 MeV. Furthermore, beta components are found having energies of about 0.94 MeV and 0.7 MeV. Gamma rays with the following energies are associated with this decay: 0.35, 0.53, 0.71, 0.87, 1.05, 1.24 and 1.30 MeV.

Introduction

The radioactive isotopes I^{134} and I^{133} decay by electron emission to their daughter nuclei Xe^{134} and Xe^{133} with the half-lives 52.5 min and 20.9 hours, respectively (cf. D. Strominger *et al.* [1]). The decay of I^{134} has previously been investigated by M. McKeown and S. Katcoff [2] with scintillation techniques. These authors have found two beta components with the energies 2.5 MeV and 1.5 MeV and three stronger gamma rays having energies of 0.86 MeV, 1.10 MeV and 1.78 MeV and, in addition, two weaker ones with the approximate energies 0.12 MeV and 0.20 MeV. McKeown and Katcoff [2] also report some coincidence experiments which show that the 2.5 MeV beta component is in coincidence with the 0.86 MeV gamma ray and that the 1.5 MeV beta component is in coincidence with gamma rays of energies larger than 1.3 MeV.

The decay of I^{133} has been studied by A. R. Brosi and P. M. Gross, Jr. [3], who have found two beta components with energies 1.4 MeV and 0.5 MeV. They also report three gamma rays with the energies 0.53 MeV, 0.85 MeV and 1.4 MeV.

In the present investigation a re-examination of the radiations from the decay of I^{134} and I^{133} has been performed.

Source preparation

The iodine isotopes in question were obtained from fission products. About 2 g of uranyl nitrate was irradiated in the Swedish reactor R1 with maximum neutron flux ($\sim 10^{12}$ neutrons/cm^2 sec). To obtain the isotope I^{134} the uranyl nitrate was irradiated for a period between five and ten minutes. Rapidly after the end of the irradiation the tellurium activity in the sample was precipitated as pure as possible. Iodine was then allowed to grow in during ten minutes. Iodine carrier was added and repeated CCl_4 extractions of iodine in the elementary state were performed. The isotope I^{133} was favourably obtained when the pile irradiation of the uranyl nitrate was continued during twenty minutes and the tellurium activity was allowed to decay for one hour before the iodine was separated.

For the beta-spectroscopic work the added quantity of iodine carrier was not allowed to exceed 200 μg. In this case the iodine was precipitated as AgI. The resulting emulsion was centrifuged off, slurried in ethyl alcohol and evaporated on a thin copper backing. The yield obtained in this process was 20–30 per cent.

An estimate of the impurities in our final sources (especially Te, Se and Br isotopes) showed that they were negligible. On the other hand, there were always present iodine isotopes with other mass numbers. Hence in sources used for studying the isotope I^{134} there was an admixture of about ten to fifteen per cent of the isotope I^{133} and about one per cent of the isotope I^{131} with the half-life 8.1 d [1].

The decay of I^{134}

Beta-ray spectrum

The spectrum of the electrons emitted in the decay of I^{134} was studied in an intermediate image beta-spectrometer of the Slätis–Siegbahn type [4] and the results are shown in Fig. 1*a*. A Fermi analysis of the beta-ray spectrum is shown in Fig. 1*b*. A resolution of the Fermi plot into components shows that the spectrum is rather complex. Earlier measurements by McKeown and Katcoff [2] have been confirmed in so far as the maximum beta energy is found to be 2.35 ± 0.15 MeV. The maximum energies of the next groups are 1.57 MeV and 1.3 MeV. Furthermore, there may be some groups with maximum energies around 1 MeV. The relative intensities of all these components are of the same order of magnitude. Finally there might be some weak components in the beta-ray spectrum with maximum energies around 0.5 MeV.

The beta-ray spectrum contains one prominent conversion peak, the energy of which is determined as 103 ± 1 keV. This peak interpreted as due to K conversion of a gamma ray with the energy 138 keV was studied separately in a double focusing beta-spectrometer. The conversion peaks due to other transitions in this decay are too weak compared to the continuous background to be seen in our experiments.

Singles gamma-ray spectrum

Fig. 2 shows the singles gamma-ray spectrum from the decay of I^{134} obtained by a scintillation spectrometer. The detector consisting of a $\varnothing\, 1\frac{3}{4}'' \times 1''$ NaI(Tl) crystal

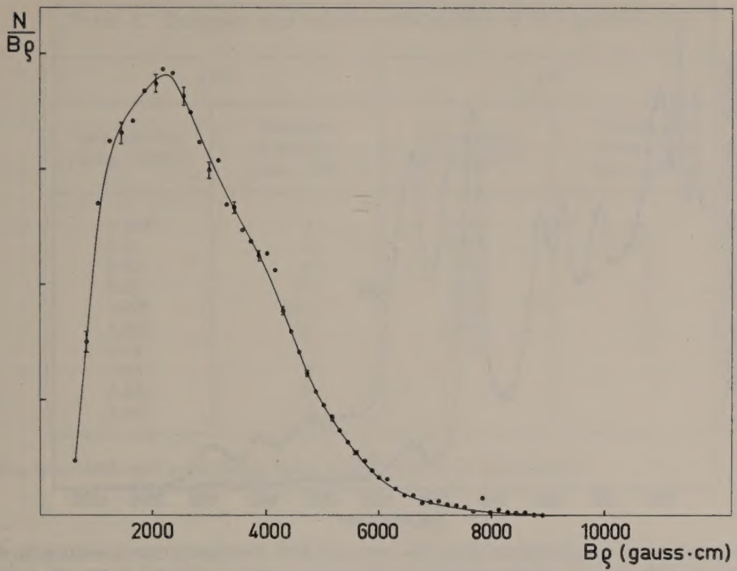

Fig. 1. (*a*) Beta-ray spectrum of the decay of I^{134} as measured in an intermediate image beta-spectrometer. The points are obtained from two partly overlapping measurements fitted together. The background, essentially due to the decays of I^{133} and I^{131}, is subtracted. The errors given for the points are calculated standard deviations. The 103 keV conversion peak mentioned in the text is not indicated in the figure, but was studied separately in a double focusing beta-spectrometer.

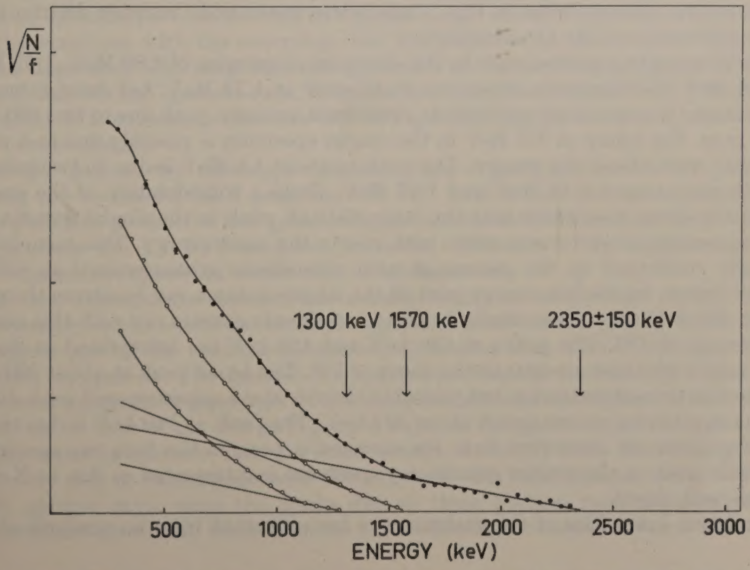

Fig. 1. (*b*) Fermi analysis of the beta-ray spectrum of the decay of I^{134}. The errors indicated for the points are calculated standard deviations, while the uncertainty in the maximum energy is estimated. Allowed beta transitions are assumed.

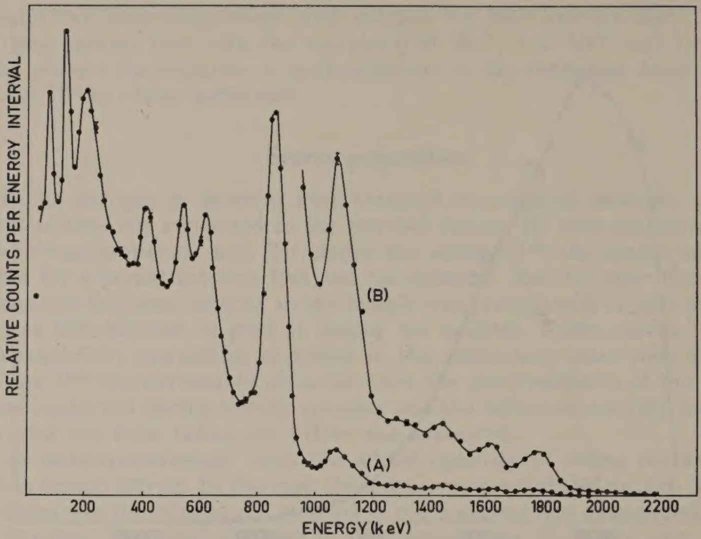

Fig. 2. Singles gamma-ray spectrum from the decay of I^{134}. The background essentially due to the decays of I^{133} and I^{131} is not subtracted. For some points statistical errors are indicated. Curve B is obtained in a longer run than curve A.

mounted on a EMI photomultiplier was shielded by about ten cm lead and the radiation was well collimated. The energy resolution of the equipment was about 8 per cent for the 662 keV gamma ray from the decay of Cs^{137}. An attempt has been made to resolve the spectrum in Fig. 2 into photo-peaks and Compton distributions and the following results are obtained.

The most energetic gamma rays in this decay have energies of 1.80 MeV, 1.62 MeV and 1.45 MeV. Furthermore, there is a small peak at 1.73 MeV, but from intensity considerations it seems most probable to consider it as a sum peak due to two 860 keV gamma rays. The bump at 1.3 MeV in the singles spectrum is possibly due to a weak gamma ray with about this energy. The peak at about 1.1 MeV is due to two gamma rays with the energies 1.14 MeV and 1.07 MeV. From a consideration of the energy resolution it seems reasonable that the large 860 keV peak in the singles gamma-ray spectrum consists of two components with nearly the same energy. This assumption is strongly confirmed by the gamma-gamma coincidence measurements as will be discussed below. In the low-energy part of the singles gamma-ray spectrum the peak at about 530 keV should essentially be due to an intense gamma ray with this energy in the decay of I^{133}. The peaks at 630 keV and 420 keV are interpreted as due to gamma rays with these energies in the decay of I^{134}. The broad peak at about 200 keV is mainly due to backscattering but probably there is also a superimposed peak due to a gamma ray having an energy of about 210 keV. The peak at 140 keV is due to the 138 keV gamma ray identified from the conversion peak in the beta-ray spectrum. The 80 keV peak in the singles gamma-ray spectrum is interpreted as due to X-rays from the lead shield.

The relative intensities of the gamma rays are estimated from an analysis of the

Table 1. Energies and relative intensities of the gamma rays.

I^{134}		I^{133}	
Gamma-ray energy (MeV)	Relative intensity $I_{0.86} = 100$	Gamma-ray energy (MeV)	Relative intensity $I_{0.53} = 100$
0.138	4	0.35	—
0.21	4	0.53	100
0.42	9	0.71	2
0.63	18	0.87	9
0.86[a]	100	1.05	1
1.07	11	1.24	2
1.14	9	1.30	4
1.45	2		
1.62	3		
1.80	4		

[a] The line width and coincidence data indicate this as a double line.

resolved gamma-ray spectrum and by use of a semi-empirical calibration curve for the photo-peak efficiency. The energies and the relative intensities are given in Table 1. The energies are in most cases believed to be correct to within 5% and the intensities to within 30%.

Coincidence measurements

Some coincidence experiments have also been carried out. The spectrum of gamma rays in coincidence with the 860 keV gamma rays shows a striking similarity to the singles spectrum with the exception that the peak due to the 1.62 MeV gamma ray seems depressed. The most interesting feature is the dominating height of the peak due to the 860 keV gamma rays. It seems that the most natural way to explain this appearance is to assume that two 860 keV gamma rays of about the same intensity are in coincidence.

In the gamma-ray spectrum obtained when recording coincidences with pulses giving rise to the 1.1 MeV peak the 860 keV peak is still the most prominent one. The peak due to the 420 keV gamma ray is emphasized, while the 630 keV peak and particularly the 1.1 MeV peak are depressed. The rest of the high-energy part of the coincidence spectrum seems also to be depressed.

In the beta-gamma coincidence measurements an anthracene crystal was used as detector for the electrons. In these experiments only pulses giving rise to the most energetic part of the continuous beta-ray spectrum were allowed to trigger the coincidence equipment. The gamma-ray spectrum obtained in this way indicates that the most energetic components of the complex beta-ray spectrum are in coincidence with one or both of the 860 keV gamma rays, as the peak due to these gamma rays is the most prominent one. To some extent, at least, these beta-ray groups are probably also in coincidence with the 420 keV, 630 keV and one or both of the 1.1 MeV gamma rays, since the peaks due to these gamma rays are present in this coincidence spectrum, while gamma rays with higher energies are depressed.

At last some observations will be mentioned from experiments with a well-type ∅ $1\frac{3}{4}'' \times 2''$ NaI(Tl) crystal. In the sum spectrum obtained with this crystal there is a surprisingly intense peak at about 530 keV. It may arise from a summing up of the 138 keV and 420 keV gamma rays, thus indicating that these two gamma rays should be in coincidence with each other. The high-energy part of the sum spectrum shows a lot of peaks indicative of the large number of states in the level scheme of the even-even nucleus Xe^{134}. A prominent sum peak appears at 1.73 keV interpreted as due to a summing up of two 860 keV gamma rays. This fact supports the assumption of two 860 keV gamma rays in coincidence. The energy of the most energetic sum peak has been determined to be 2.92 MeV.

DISCUSSION

It is very difficult to propose a decay scheme for the isotope I^{134} from the experimental data reported above. However, some general features of the structure of this decay will be discussed on the basis of our results (cf. Fig. 3). It seems natural from intensity considerations to let one of the 860 keV gamma rays connect the first excited state with the ground state as has also been proposed by McKeown and Katcoff [2]. Due to the strong coincidence relation between the two 860 keV gamma rays they seem to be emitted in cascade from a level with the energy 1.73 MeV. According to the conclusions that can be drawn from the beta-gamma coincidence experiments it seems probable that the most energetic beta components feed this 1.73 MeV level and (or) levels with higher energies. This fact makes it possible to give a lower limit for the value of the beta disintegration energy of this decay to 4.08 MeV. R. W. King [5] has reported 3.4 MeV for this Q_{β^-} value on the basis of

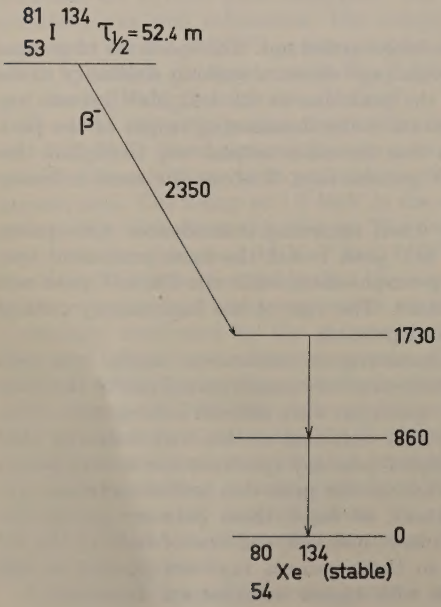
$^{134}_{53}I_{81}$ $T_{1/2}$=52.4 m
β^-
2350
1730
860
0
$^{134}_{54}Xe_{80}$ (stable)

Fig. 3. A partial decay scheme for I^{134}.

the measurements of McKeown and Katcoff [2]. From beta energy systematics plotted in the manner of K. Way and M. Wood [6] one gets a Q_{β^-} value of about 4.2 MeV. Approximately the same value can also be obtained from calculations with a semi-empirical mass formula. This is therefore in good agreement with our interpretation of the experimental results.

Furthermore, the sum spectrum from the well-crystal experiments indicates that the highest state in the level scheme of Xe^{134} which is fed with a considerable intensity ought to have an energy of about 2.9 MeV. According to the Fermi analysis of the beta-ray spectrum the actual beta component has an energy of about 1 MeV. This is consistent with the assumption that the most energetic beta component feeds a level with an energy of roughly about 2 MeV.

The experimental data are still too incomplete to permit conclusions about the positions of the other gamma rays in the level scheme.

The decay of I^{133}

Beta- and gamma-ray spectrum

In accordance with the results of Brosi and Gross [3] and others the beta-ray spectrum was found to consist of a main beta component, the maximum energy of which was determined as 1.27 ± 0.05 MeV (cf. Fig. 4*a* and 4*b*). The Fermi analysis of the measured beta-ray spectrum also indicates the existence of a weak beta component at 0.94 MeV. There may be other components of comparable intensity and with maximum energy of 0.5–0.7 MeV. The appearance of the Fermi plot in Fig. 4*b*

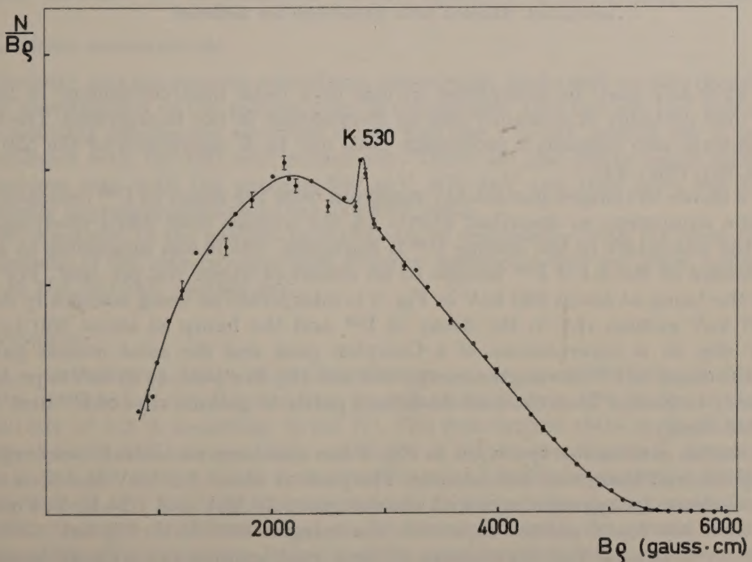

Fig. 4. (*a*) Beta-ray spectrum from the decay of I^{133} obtained in an intermediate image beta-spectrometer. The background mainly due to the decay of I^{131} is subtracted. The errors indicated for the points are calculated standard deviations.

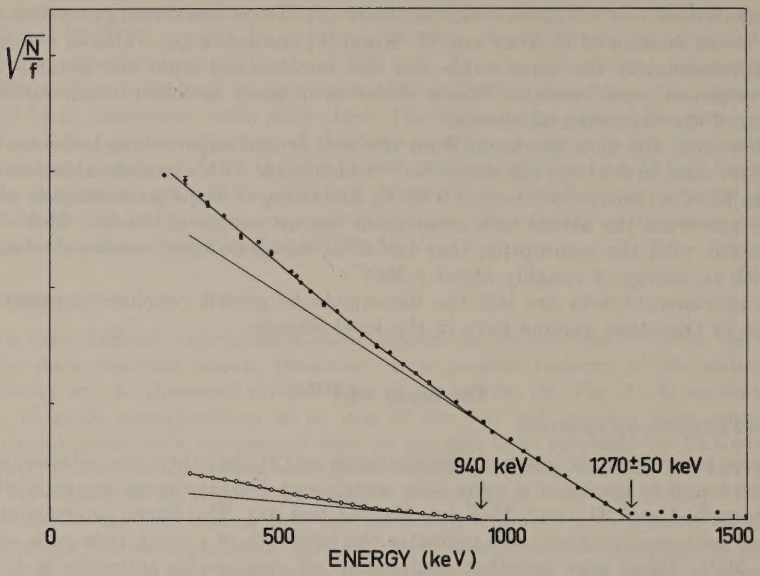

Fig. 4. (*b*) Fermi analysis of the beta-ray spectrum from the decay of I^{133}. The errors indicated for the points are calculated standard deviations, while the uncertainty in the maximum energy is estimated. Allowed beta transitions are assumed.

above 1270 keV may be interpreted as due to a weak beta component of higher energy but probably it is mainly due to fluctuations in the background. The beta-ray spectrum also contains a prominent peak due to *K* conversion of the 530 keV gamma ray (Fig. 4*a*).

Fig. 5 shows the singles gamma-ray spectrum from the decay of I^{133} recorded with the same equipment as described above. In the sources used when studying this decay the admixture of the isotope I^{134} is negligible, but it was impossible to avoid the presence of the 8.1 d I^{131} isotope to an extent of about ten per cent. For that reason the bump at about 630 keV in Fig. 5 is interpreted as being essentially due to the 637 keV gamma ray in the decay of I^{131} and the bump at about 350 keV as mainly due to a superposition of a Compton peak and the most intense gamma ray in the decay of I^{131} having the energy 364 keV [1]. The peak at 80 keV is probably due partly to X-rays from the lead shield and partly to gamma rays of I^{131} and Xe^{133} with this energy.

The singles gamma-ray spectrum in Fig. 5 has also been tentatively resolved into photo-peaks and Compton distributions. The peak at about 1.3 MeV has been interpreted as due to two gamma rays with the energies 1.30 MeV and 1.24 MeV. Furthermore, there are found gamma rays with the energies 1050 keV, 870 keV, 710 keV and 530 keV. In addition, there seems to be a weak gamma ray with an energy of about 350 keV for which there is evidence in the gamma-gamma coincidence spectrum discussed below. The energies and the estimated relative intensities for these gamma rays are given in Table 1.

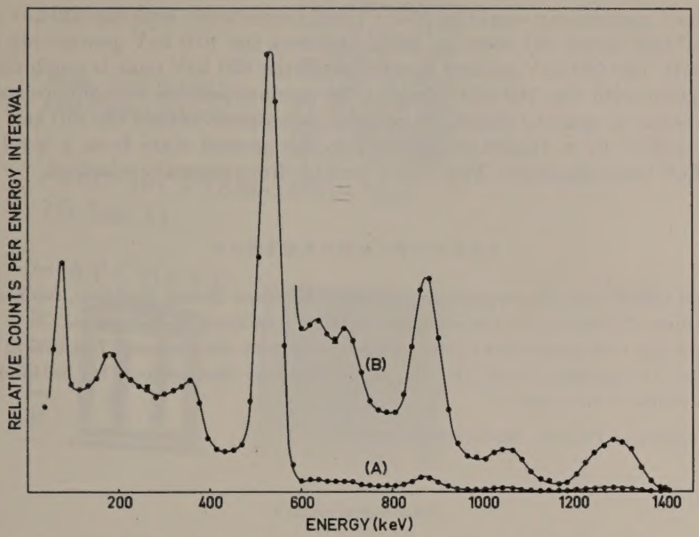

Fig. 5. Singles gamma-ray spectrum from the decay of I^{133}. The background mainly due to the decay of I^{131} is not subtracted. For some points statistical errors are indicated. Curve B is obtained in a longer run than curve A.

Coincidence measurements

The only gamma-gamma coincidence experiment performed on the decay of I^{133} is an investigation of the gamma rays in coincidence with the 530 keV gamma ray. The resulting gamma-ray spectrum shows that the 710 keV gamma ray is in strong coincidence with the 530 keV gamma ray. There are also photo-peaks present due to gamma rays with the energies 330 keV, 870 keV and 1050 keV, but they are markedly depressed relative to the 710 keV peak.

The spectrum of the gamma rays that are in coincidence with the most energetic component of the beta-ray spectrum contains essentially only one peak, namely that due to the 530 keV gamma ray.

DISCUSSION

As a summing up of the experimental data some properties of the nucleus Xe^{133} will be discussed. Xe^{133}, the daughter nucleus of the isotope I^{133}, decays to Cs^{133} with a half-life of 5.3 d according to ref. [1]. The first excited state in Xe^{133} having an energy of 233 keV decays with a half-life of 2.3 d according to I. Bergström [7] and is fed by a very weak beta component. As has been suggested by M. Goldhaber and R. D. Hill [8] it seems natural to assume the second excited state to have an energy of 530 keV and to be connected with the ground state by the intense 530 keV gamma ray. From intensity considerations it is necessary to assume that the 1.27 MeV beta component feeds the second excited level and this is also consistent with the results from the beta-gamma coincidence measurement. The positions of the remaining gamma rays in the decay scheme are very uncertain.

The 710 keV gamma ray ought to be in direct coincidence with the 530 keV gamma ray. Brosi and Gross [3] seem to have assumed the 870 keV gamma ray to be in cascade with the 530 keV gamma ray, but since the 870 keV peak is much depressed in comparison with the 710 keV peak in the gamma-gamma coincidence spectrum, this suggestion is open to doubt. A possible assumption is that the 870 keV gamma ray corresponds to a transition directly to the ground state from a level fed by the 0.94 MeV beta conponent. This is also possible from intensity relations.

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